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Stability Test of Liquid Flow Standard Facility with a Flowmeter

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Abstract

In order to assess flow stability reasonably, this paper presents a new test method for flow stability of liquid flow standard facility with a flowmeter, demonstrates the basis of this method, proposes the detailed implementation measure and key process in flow stability test, and discusses the calculation method of flow stability parameters.

Keywords: Metrology; Flowmeter method; Liquid flow standard facility; Stability; Random process;

1. Introduction

Flow stability is a performance index for measuring the working stability of liquid source and baffles of the pipeline of liquid flow standard facility as well as an important parameter in assessing the metering performance of liquid flow facility, which influences the unitarity and accuracy of the value transmission and source-tracing of liquid flowmeter. In previous rules, the uncertainty of facility attracts much attention because of the included component flow stability. At present, flow stability is regarded as an independent test item in international standards and metrology verification regulations; and there is no specific index dividing line in combined uncertainty of facility, nor is the component uncertainty of this test item included. Therefore, there is a lack of attention to the flow stability. However, when the stability exceeds a certain limitation, the test result of the indication error of the tested flowmeter might go wrong. Thus, it becomes necessary to test the flow stability of the facility according to the requirement of the flowmeter. In addition, all the verification regulations (or standards) for flowmeter stipulate that the repeatability of flowmeter should be 1/3~1/5 of the maximum allowable error [1] [2]. Facility with low limitation to flow stability (i.e. the uncertainty of flow repeatability of the facility) can meet the repeatability requirement of the flowmeter.

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There are two test methods of flow stability of liquid flow standard facility, namely, the flow stability during the accumulative time and that between each accumulative time. While the former is a well known one, this paper only studies the calculation method of the uncertainty of the dynamic flow stability of the facility with a flowmeter.

2. Test of facility stability

2.1 Testing as per the position

The structural principle of liquid flow standard facility is shown as Figure 1. Set that the second section Ⅱ—Ⅱ is chosen at the outlet of the tested section. The gauge pressure is 0 and the influence of inertia is excluded; the water surface of water tower (or the water-air interface of the pressure stabilizer) is Section Ⅰ—Ⅰ. Taking the outlet Ⅱ—Ⅱ as the base level, the Bernoulli's equation of Ⅱ—Ⅱ and Ⅰ—Ⅰ is listed as follows [3]:

$$Z_1+\frac{P_1}{r}+\frac{v_1{}^2}{2g}=Z_2+\frac{P_2}{r}+\frac{v_2{}^2}{2g}+\left(\sum_{i=1}^{n}\lambda_i\frac{L_i}{d_i}+\sum_{i=1}^{n}\zeta_i\right)\frac{v_2{}^2}{2g} \tag{1}$$

Of which, Z_1 is the potential energy at one point of water tower, $Z_1=h$; P_1 is the pressure of the water surface of water tower, $P_1=P_a$; v_1 is the flow rate at one point of the water surface of the water tower; Z_2 is the effective water head height, Z_2=0; P_2 is the gauge pressure at the outlet of the tested section, $P_2=P_a$; v_2 is the flow rate at the outlet of the tested section; g is the acceleration of gravity; ζ is the local resistance coefficient; λ is the distance resistance coefficient; L and d is the pipe length and the inner diameter of this position respectively.

Because $P_1=P_2=P_a$, $Z_2=0$, $Z_1=h$, $v_1=0$, equation (1) becomes:

$$\begin{cases} h=\dfrac{v_2^2}{2g}+\left(\displaystyle\sum_{i=1}^{n}\lambda_i\frac{L_i}{d_i}+\sum_{i=1}^{n}\zeta_i\right)\dfrac{v_2^2}{2g}=\left(1+\displaystyle\sum_{i=1}^{n}\lambda_i\frac{L_i}{d_i}+\sum_{i=1}^{n}\zeta_i\right)\dfrac{v_2^2}{2g} \\ v_2=\left[2gh\Big/\left(1+\displaystyle\sum_{i=1}^{n}\lambda_i\frac{L_i}{d_i}+\sum_{i=1}^{n}\zeta_i\right)\right]^{\frac{1}{2}} \end{cases} \tag{2}$$

Flow formula:

$$q_{\mathrm{v}}=F_2v_2=F_2\times\left[2gh\Big/\left(1+\sum_{i=1}^{n}\lambda_i\frac{L_i}{d_i}+\sum_{i=1}^{n}\zeta_i\right)\right]^{\frac{1}{2}} \tag{3}$$

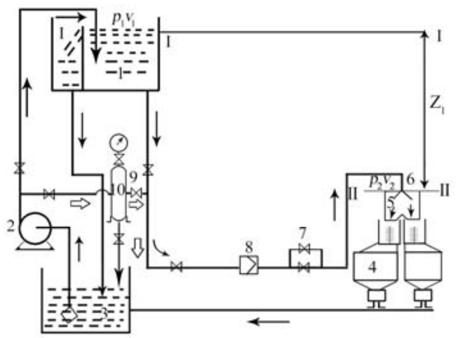

Figure 1 Water Tower or Static Volume with Volume Press-stabilizing Method or Weighing Liquid Flow Facility

Notes:
1-Water Tower; 2-Water Pump; 3-Basin; 4-Working Measuring Vessel; 5-Commutator;6-Nozzle; 7-Flow Regulating Valve; 8-Tested Flowmeter; 9-Stop Valve; 10- Pressure Stabilizer

When the facility works, h is a pulsating quantity; λ is related to the pipe diameter, relative roughness and Reynolds number. As the flow rate is changing, ζ is also regarded as a pulsating quantity. The opening change of valves and other parts for looseness (for the reason of shock) may result in the pulsation of local resistance coefficient. As there are different valves and other resisting parts with different diameters at positions, it causes the different pulsations of ζ and flow rate v as well as the different pulsations of flow q_v . Therefore, it's necessary to test the flow stability as per the position.

2.2 Choice of working measuring vessel

When the stability of maximum flow of facilities at positions is tested, the maximum range of the biggest working measuring vessel (or scale) should be adopted; while the minimum range of the smallest working measuring vessel (or scale) should be adopted for the test of the stability of the minimum flow of the position. Generally, each position corresponds to a nominal diameter and the flowmeter with different nominal diameters has a fixed applicable range of flow. At maximum flow, the filling time of the biggest working measuring vessel should be no less than 30s; for extending the test time to obtain enough measuring data, the maximum range of the biggest working measuring vessel at the position should be applied. At minimum flow, if the filling time of the minimum range of the smallest working measuring vessel is no less than 60s, the application of minimum range is not necessary but depends on the specific test time.

2.3 Choice of flowmeter

Electromagnetic flowmeter or turbine flowmeter can be applied in flow stability test.

Turbine flowmeter possesses high accuracy, and grade 0.2 (repeatability over 0.1%) can be chosen in China for it is especially suitable for position with a diameter of less than 200 mm. Although electromagnetic flowmeter possesses relatively low accuracy, it can satisfy the requirement when applied at fixed positions, and it is especially suitable for positions with large diameter (DN>200mm).

2.4 Test method of flow stability

Install a turbine flowmeter (or electromagnetic flowmeter) at tested flowmeter in the tested section of the position; adjust the flow to the maximum value which should correspond to the design value; and then circulate for 10 min to create a condition for stable flow.

Control the commutator and start the timer simultaneously; then read the indication of the flowmeter. No less than 60 indications ($n \geq 60$) per minute should be obtained within normal flow measuring time.

Make the printer record instantaneous flow value while the commutator and timer start and record once per second; in the selected measuring time interval T, ensure to obtain n ($n \geqslant 60$) indications with a constant interval, i.e. $T \geqslant 60$s.

n indications ($n \geqslant 60$) are not confirmed quantitatively, but qualitatively. Strictly speaking, the flow value changes all the time. If less data are obtained, they are not enough to reflect this change, then the calculation of some characteristic quantities in describing flow-time process, such as mean value, correlation function and spectral density function will distort. But n can not be too big because of the restriction of the functions of working measuring vessel (weighting container) and flow printer.

3. Confirmation of ergodic random process

3.1 Stationary random process

If all the characteristic quantities of random process $x(t)$ are irrelevant to time t, $x(t)$ is called a stationary random process; otherwise, it is a non-stationary random process.

Stationary conditions: the mean value is a constant, the **variance is a constant** and autocorrelation function $K_x(t, t+\tau)$ doesn't change as the change of t, namely,

$$K_x(t, t+\tau) = K_x(\tau) \tag{4}$$

So the main condition of stationary random process is that the autocorrelation function is a univariate function $K_x(\tau)$.

Characteristic quantities of stationary random process:

①Mean value： $m_x(t) = \mathrm{E}\left[x(t_1)\right] = \mathrm{E}\left[x(t_2)\right] = \mathrm{cons}\tan \mathrm{t}$ (5)

②Variance： $D\left[x(t)\right] = K_x(t,t) = K_x(0) = cons\tan t$ (6)

③Autocorrelation function： $K_x(\tau) = \mathrm{E}\left[x(t), x(t+\tau)\right]$

$$\rho_x(\tau) = \frac{K_x(\tau)}{\mathrm{D}_x} \tag{7}$$

In actual engineering measurement, the form of random function is unknown in advance in most occasions, but a sample set of random function is measured and obtained through test. Then characteristic quantities can be obtained through test result.

Take $t_1, t_2, \cdots t_n$ equidistantly and take n function values for each sample of the N samples in $x(t)$, which are $x_i(t_1), x_i(t_2), \cdots x_i(t_n)$. The value of n must be big enough to dozens or hundreds according to the characteristics of the researched random function.

The characteristic quantity of stationary process is estimated through algebraic sum.

Mean value:

$$m_x(t_k) = \frac{1}{N}\sum_{i=1}^{N} x_i(t_k) \tag{8}$$

Standard deviation：

$$\sigma_x = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left[x_i(t_k) - m_x(t_k)\right]^2} \tag{9}$$

Autocorrelation function：

$$\rho_x(t_x,t_l)=\frac{K_x(t_x,t_l)}{\sigma_x(t_x)\cdot\sigma_x(t_l)} \tag{10}$$

Of which, $i=1,2\cdots\cdots N$； $k=1,2\cdots\cdots n$； $t_l=t_k+\tau$ (τ is the time interval).

The method of confirming characteristic quantities of stationary random process through test is applicable to every process: random process or non-random process. According to the calculation result, if autocorrelation function decreases as time interval elongates, then it is a stationary random process; otherwise, it is a non-stationary random process[4-7].

3.2 Ergodic random process

The sufficient condition of stationary random process with ergodicity is that its correlation function is close to 0 when τ increases, that is,

When $\tau\to\infty$， $K_x(\tau)\to 0$；

If when $\tau\to\infty$， $K_x(\tau)$ is close to a constant, it's a non-ergodic process.

$$m_x=\frac{1}{n}\sum_{i=1}^{n}x(t_i) \tag{11}$$

$$D_x=\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i-m_x\right)^2=\sigma_x{}^2 \tag{12}$$

$$\rho_x(\tau)=\frac{1}{n-m}\frac{1}{D_x}\sum_{i=1}^{n-m}\left(x_i-m_x\right)\left(x_{i+m}-m_x\right) \tag{13}$$

Of which, $\tau=m\left(\frac{\mathrm{T}}{n}\right)$， x_i and x_{i+m} are function values of two random points with a mutual distance of τ , m is the sampling point number between x_i and x_{i+m}, $m=0,1,2\cdots,n$.

4. Calculation of flow stability of facility

According to a group of known test data manifesting the flow change at a position of one facility as time changes (See Table 1), confirm the fluctuation condition of "basically with co-axis and constant amplitude", which is based on ergodic random process. The total measuring time is *T*=60s and sampling is conducted per second, namely, *n*=60. Then calculate the flow stability of facility.

Of which, $\tau=m\left(\frac{\mathrm{T}}{n}\right)=\frac{60}{60}m=m$; *T* is the total measuring time, (s); τ represents the difference of the serial numbers of two sampling periods, (s); *m* represents the ratio of the difference of the serial numbers of two sampling periods to the measuring interval, *m*=0, 1, …, *n*;

$\rho(1)=\frac{1}{59}\frac{1}{(0.0732312\ )}\sum_{i=1}^{59}\left(x_i-24.410\right)\left(x_{i+m}-24.410\right)=-0.1704$, $\rho(2)=-0.0268$, $\rho(3)=0.1963$; $\rho(4)=0.0286$, …ρ（τ）=

So $m_{\min} = 1$ (When m=1, $\rho < 0.1$)

Table 1 Data of Flow Stability Test ($q_{\max} = 24.00\mathrm{m}^3/\mathrm{h}$)

No (t)	Flow (x/m^3·h^{-1})	No (t)	Flow (x/m^3·h^{-1})	No (t)	Flow (x/m^3·h^{-1})	No (t)	Flow (x/m^3·h^{-1})	No (t)	Flow (x/m^3·h^{-1})
1	24.348	13	24.335	25	24.581	37	24.207	49	24.905
2	24.717	14	24.558	26	24.912	38	24.453	50	25.156
3	24.190	15	24.286	27	24.135	39	24.468	51	24.129
4	24.371	16	24.079	28	24.678	40	24.435	52	24.260
5	24.146	17	24.572	29	24.765	41	24.118	53	24.284
6	24.359	18	24.949	30	24.421	42	24.390	54	24.271
7	24.502	19	24.022	31	25.029	43	24.280	55	24.495
8	24.150	20	24.698	32	24.124	44	24.035	56	24.174
9	24.421	21	24.207	33	24.776	45	24.314	57	24.486
10	24.201	22	24.493	34	24.364	46	24.797	58	24.238
11	24.852	23	24.395	35	24.673	47	24.583	59	24.192
12	24.222	24	24.348	36	24.176	48	24.057	60	24.834

Attenuation ratio is:

$$\zeta = \frac{T}{n}\sum_{i=1}^{m_{\min}} \left|\rho_{\mathrm{m}}(\tau)\right| = \frac{60}{60}\left|-0.1704\right| = 0.1704 \ \mathrm{s}$$

$$\sigma = \left(2D_{\mathrm{x}}\zeta / T\right)^{\frac{1}{2}} = (2.00\times 0.0732312\times 0.1704/60)^{\frac{1}{2}} = 0.0204\mathrm{m}^3/\mathrm{h}$$

Standard deviation is:

$$\sigma = \left(2D_{\mathrm{x}}\zeta / T\right)^{\frac{1}{2}} = (2.00\times 0.0732312\times 0.1704/60)^{\frac{1}{2}} = 0.0204\mathrm{m}^3/\mathrm{h}$$

$$U_{\mathrm{rA}}(q) = 2\times\frac{\sigma}{m_{\mathrm{x}}}\times 100\% = 2.00\times\frac{0.0204}{24.410}\times 100\% = 0.2\% \ (K_{\mathrm{p}} = 2)$$

Stability of dynamic flow is:

$$U_{\mathrm{rA}}(q) = 2\times\frac{\sigma}{m_{\mathrm{x}}}\times 100\% = 2.00\times\frac{0.0204}{24.410}\times 100\% = 0.2\% \quad (K_{\mathrm{p}} = 2)$$

Adjust the flow to the minimum flow and confirm the uncertainty of stability under minimum flow according to the test procedures; compare the uncertainties of stability at maximum and minimum flow respectively, and select the uncertainty with a bigger absolute value as the flow stability of the facility.

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